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WHITE PAPER

Confused About Standardizing V2G? You're Not Alone!

This paper reviews the current state of standardization of V2G technologies and highlights the technical issues that will need to be resolved to enable mass adoption of Vehicle to Grid (V2G) in the US. It also highlights QualityLogic's contributions to an interoperable EV communications infrastructure.

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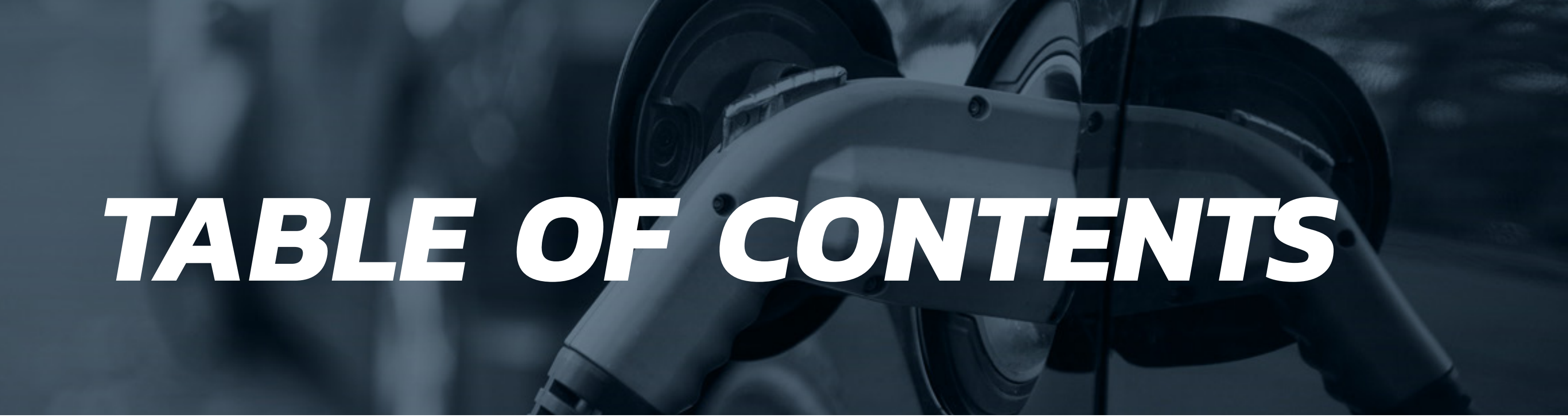

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Executive Summary:

One of the critical obstacles to realizing the potential of Vehicle-to-Grid (V2G) applications[1] is the standardization of the technology that enables efficient, low-cost, mass adoption of V2G business and technology. The current trajectory of EV communications in the US is to focus on standardizing the charging infrastructure without adequate attention to its impact on the adoption of V2G. This presents a significant barrier to adopting V2G technology at scale.

1. For instance, EPRI estimates that V2G applications for the state of California could generate up to $1B in annual benefits for the state. See Open Standards-Based Vehicle-to-Grid: Value Assessment (epri.com). The term "VGI" denotes any method of using EV charging/discharging for grid support.

Background: What is V2G?

Vehicle-Grid Integration (VGI) is defined as altering the time, rate of charge, level of charge, reverse power flow, etc., such that it provides net benefits to both the electrical grid operations and to the EV owner.[2] VGI includes two basic use cases: managing the charging of EVs to reduce peak demand (V1G) and using the batteries in the EVs as energy and power sources to support grid operations (V2G). V2G is further divided into a V2G-DC use case and a V2G-AC use case.

V2X is the use of EV batteries to support power needs for buildings and other loads (but certainly can include V2G). The Ford F150 Electric Truck has popularized this concept for an emergency power source for residential customers during blackouts.[3] There are differences in the technology, certifications and interconnection requirements for V2X but the on-board battery/inverter technology offers a short path to providing interconnected grid support capabilities from the same EV.

V2G-DC is comparable to a battery storage resource on the grid with a bi-directional AC-DC inverter in the charging station (EVSE or EV Supply Equipment). DC power is supplied to the EV battery and can be reversed as exported DC power to the EVSE.

V2G-AC on-the-other-hand is enabled when an advanced bi-directional AC-DC inverter is on the EV itself as in the case of the Ford F-150 Lightning (Ford is not currently doing V2G, but the on-board inverter enables the potential for such). There is an on-going debate about whether it makes more sense to build an inverter into an EV or rely on the EVSE for AC-DC conversion.[4] Ford is changing the arguments.

2. See for instance the Final Report at GW_VehicleGrid-Integration-Working-Group.pdf (gridworks.org). The Report quotes CA Law defining VGI.
3. What Is V2H? V2G? V2V? Ford's Electric Lightning Pickup Truck Spreads The Power Around (forbes.com)
4. On-board V2G versus Off-board V2G (AC versus DC) | News | pr-electronics.nl

Glossary of Terms

1. A **standard** is an internationally adopted agreement, typically drafted and approved by IEEE, IEC, ISO, SAE, etc. These are internationally recognized standards organizations (ISO)
2. A **communications "protocol"** is simply a way of standardizing how machines communicate with each other– e.g., TCP/IP, Wi-Fi. Sometimes called a "Transport Protocol."
3. A **messaging protocol** is a standard agreement on the information format and meaning that is communicated between two devices to accomplish specific applications – e.g., OpenADR, IEEE 2030.5, DNP3, SunSpec
4. A **use case** can be considered as an application and includes actors, behaviors and interactions between them
5. A **DER control architecture** is the reference design or architecture for the communications between a distribution utility and DER being managed
6. **DER** is a Distributed Energy Resource and could be solar, battery storage, an EV in V2G mode, diesel generator or other "distributed" source of power and energy, probably behind a customer meter.
7. **DERMS** is a DER Management System and is a term that has different meanings to different participants. We find it easiest to think of a DERMS as the utility system that integrates all of the information about DER resource capabilities, grid topology, customer DER programs and grid operating requirements in order to determine the optimum deployment of available DER (and DR) resources to support grid operations. A DERMS is also responsible for monitoring and dispatching DER behaviors based on the multiple factors.
8. **Profile** is a subset of a standard that enables implementation and certification of a specific use case or set of related use cases – e.g., DER in CSIP.

An advanced inverter in the EVSE enables the combination of an EVSE and EV battery to be treated as a behind-the-meter storage system and interconnected under a state's Interconnection tariff. If there is an adequate business model for doing so, EV and charging infrastructure owners can benefit from allowing the EVs to provide grid support services in the appropriate circumstances.

An emerging V2G architecture is what some call a "split inverter" where some grid support functions are on the EVSE and others are in the EV itself. This model is receiving more attention as a method to reconcile a charging infrastructure that does not support V2G with the opportunities to implement V2G use cases in the current infrastructure.

What About V1G?

A relatively straight-forward integration of EVs and grid operations is the management of the charging cycle as a flexible load (often called demand response or DR) resource. While it can be a valuable DR resource it is significantly different from V2G:

- Demand Response does NOT include energy export and is not subject to interconnection agreements. The primary form of management is the charging schedule or a price signal, while rate of charge can also be used to fine tune the demand that EV charging places on the electrical system.

EV Specific Terms

- **Vehicle-Grid Integration (VGI)** is defined as "*...any method of altering the time, charging level, or location at which grid-connected electric vehicles charge or discharge, in a manner that optimizes plug-in electric vehicle interaction with the electrical grid and provides net benefits to ratepayers by doing any of the following: (a) increasing electrical grid asset utilization; (b) avoiding otherwise necessary distribution infrastructure upgrades; (c) integrating renewable energy resources; (d) Reducing the cost of electricity supply; and (e) offering reliability services consistent with Section 380 of the Independent System Operator tariff.*"[5]
- **V1G** is the management of the charging characteristics, rate and time of charging, etc., in response to electrical grid demand management requirements.
- **V2X** is the use of EV batteries to support power needs for buildings and other loads independent of the electrical grid operations. V2G is included in V2X.
- **V2G-DC** is comparable to a battery storage resource on the grid with a bi-directional AC-DC inverter in the charging station (EVSE or EV Supply Equipment). DC power is supplied to the EV battery and can be reversed as exported DC power to the EVSE and then AC to the grid, subject to utility interconnection requirements and available energy for export.
- **V2G-AC** is enabled when an advanced bi-directional AC-DC inverter is on the EV itself. AC power can be exported from the EV to the electrical grid directly (through the EVSE), subject to utility interconnection requirements and available energy for export.
- **V2G-Split Inverter** is where some grid support functions are on the EVSE and others are in the EV itself. This is a more complex technology and may require interconnection certifications on specific EVSE-EV combinations, limiting the potential application of this approach.
- **Charge Network Operator (CNO)** manages EVSEs and may also source and install a network of charging stations.
- **EV Charging Station** is a term used to denote a single EV charger or a station with multiple EV charging stations (analogous to a traditional gas station). At this early stage in the EV industry, we can expect different uses of this term.
- **Electric Vehicle Supply Equipment (EVSE)** is a single charging station that could have multiple ports, depending on design. The simplest definition is to consider an EVSE the single source of power for a single connected EV. Charging stations are being standardized as to level of charging capability – Level 1, Level 2, DC Fast Charging, etc.
- **Bidirectional Electric Vehicle Supply Equipment / Interconnection Systems Equipment (BEVSE/ISE)** - equipment that facilitates AC charging for electric vehicles from the EPS as well as interactive AC export from the EV that operates in parallel with the EPS, using on-board EV inverters / power converters.

5. Final Report of the California Joint Agencies Vehicle-Grid Integration Working Group, June 30, 2020. GW_VehicleGrid-Integration-Working-Group.pdf (gridworks.org).

- Managed Charging programs typically are not mandated for customers but rather use incentives to solicit participation.
- The communications (between grid operator and EVSE/EV resources) for Managed Charging programs is becoming more standardized but a great number of such programs use proprietary signaling protocols. OpenADR is the most popular standard protocol for all forms of DR including Managed Charging.
  » Programs may use direct event signals with customers participating in managed charging programs. The signals are typically schedules, rates and opt-in/opt-out.
- Managed Charging Programs depend on aggregators or cloud-based interfaces to a portfolio of EV (and other) participating resources.

The Smart Energy Power Alliance has published an excellent report on Managed Charging for those looking for further information.[6]

For this paper, the focus is on V2G and we are not addressing Managed Charging because the technology, grid codes and programs are fundamentally very different. A V2G capable system could also be a Managed Charging resource but it may require two different systems and protocols to achieve.

6. The State of Managed Charging in 2021 | SEPA (sepapower.org).

Relevant Standards to Know

Below is a list of the standards most relevant to V2G applications in the US. We dive deeper into each on page 22.

- **OpenADR**
- **IEEE 2030.5**
- **DNP3**
- **SunSpec Modbus**
- **OCPP**
- **ISO 15118**
- **UL 1741 SB**
- **UL 1741 SC**

V2G Opportunities and Challenges

A 2019 EPRI study[7] of the V2G opportunity in California concluded that the benefits to the state could be as much as $1 billion per year by 2030, significantly greater than V1G technology and programs can deliver.

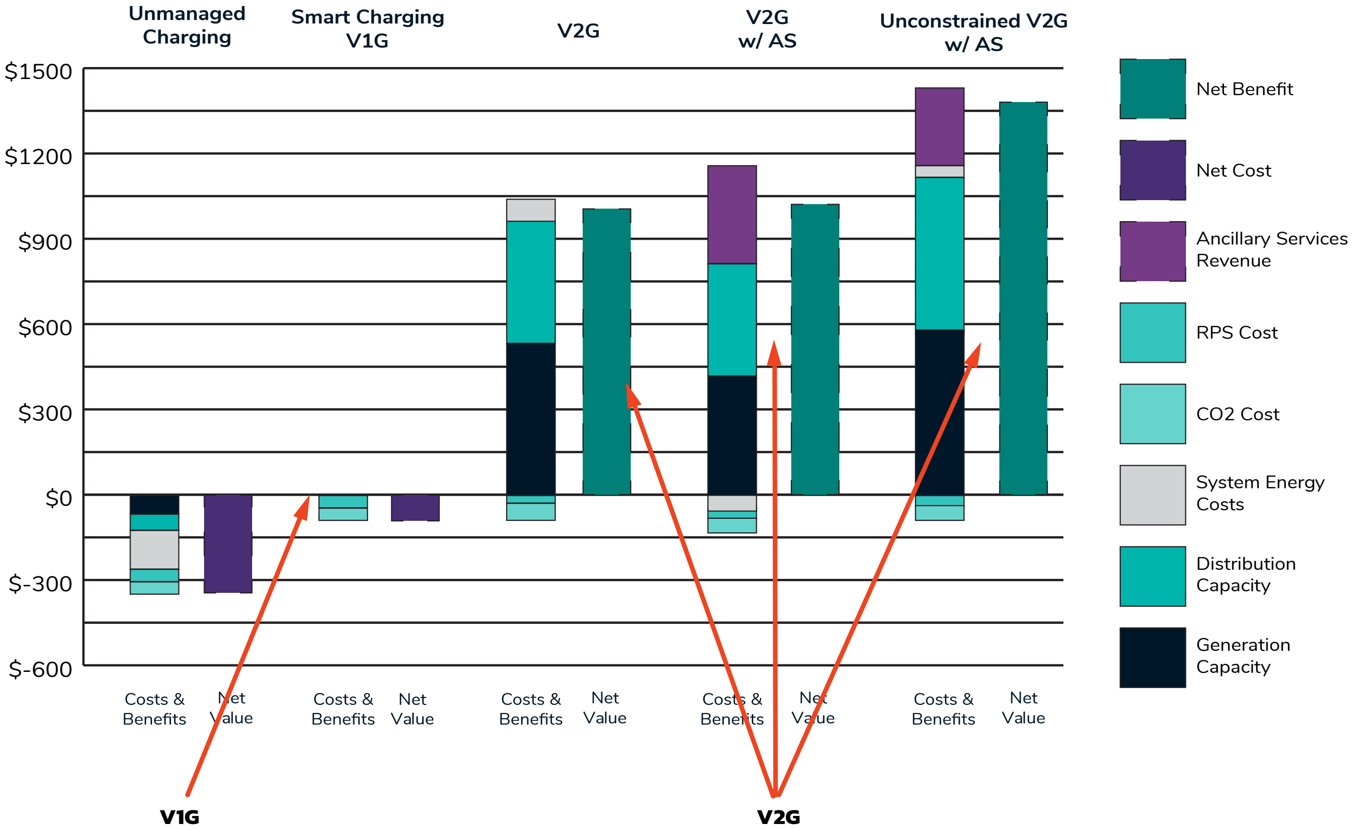


Figure 1: EPRI CA study on V2G results.

The EPRI study looked at 5 scenarios and did a detailed estimate of the costs and benefits for each. Unmanaged Charging is a net cost to California ratepayers because of the added infrastructure costs and estimated charging schedule loads. Managed Charging (V1G) reduces the net costs significantly but is still a small net cost to Californians, presumably a modest "tax" to decarbonize the transportation sector.

The base V2G scenario provides valuable services to the distribution operator such as solar overgeneration mitigation. If Ancillary Services (e.g., frequency regulation to the CAISO market) are included, the value of V2G increases further. However, ancillary services of EV batteries are typically constrained by the state of charge requirements[8] of the EVs themselves. Removing such constraints can add even more value to the use of EVs as V2G Distributed Energy Resources (DER).

7. Open Standards-Based Vehicle-to-Grid: Value Assessment (epri.com)
8. These constraints are a function of battery degradation in V2G as well as minimum charge required for both battery life and transportation use. Without these constraints, V2G can address additional value opportunities.

A recent EPRI analysis[9] estimated the potential capacity contribution from EVs with V2G compared to the annual peak electricity demand in the US..

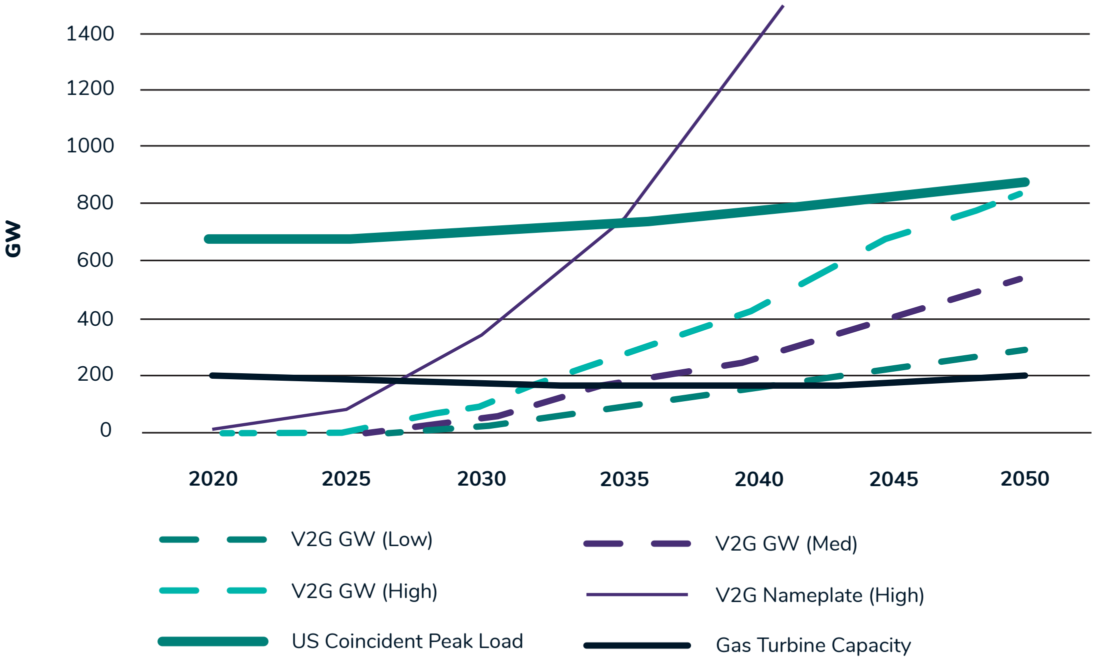


Figure 2: Projected Vehicle to Grid Capacity.

Most notable, the potential V2G energy available by 2030 could be as much as all the Gas Turbine Generation Capacity in the US. By 2040, as much as 50% of the total US Peak Load could be available from V2G resources.

However, realizing the potential for V2G requires the optimum regulatory and business policies and standardized, scalable, interoperable technology. The key to scaling a complex eco-system like V2G with potentially hundreds of EV, EVSE, Charging Network Operator (CNO) and other participants requires standardization and interoperability maturity that is only now being addressed.

A further technical barrier for V2G in the US is the pending large-scale investment in a charging infrastructure that is fundamentally incompatible with the requirements of a US V2G infrastructure today.

The goal of this paper is to explore the emerging standards for V2G and the technical challenges faced by the industry in achieving the efficient, mass scale of V2G in North America.

9. Presented at an October, 2022 EPRI Webex. Based on EIA projections of EV populations.

V2G Architectures and Standards

The V2G communications and functional architecture consider all the actors in managing EVSE-EV systems as utility grid support DERs. The goal of such an architecture is to standardize how a grid operator can access and manage EV batteries when needed and when available for grid support operations. The primary communications architecture is shown in Figure 3 and consists of a System Operator communicating to an intermediary 3rd party system (aggregator, charge network operator, site controller, etc) that directly manages the EVSEs interconnected to the grid.

From a grid operator perspective, the EVSE is the interface to an interconnected DER for purposes of energy export from a connected EV battery. The specific details of an architecture depend on where the AC-DC inverter is located, the control system for the inverter behavior and the interface to the utility.

An alternative architecture is to use the EV proprietary Telematics communications network to manage V2G applications. The lack of standardization of Telematics creates a serious challenge to V2G and this paper does not address this architecture.

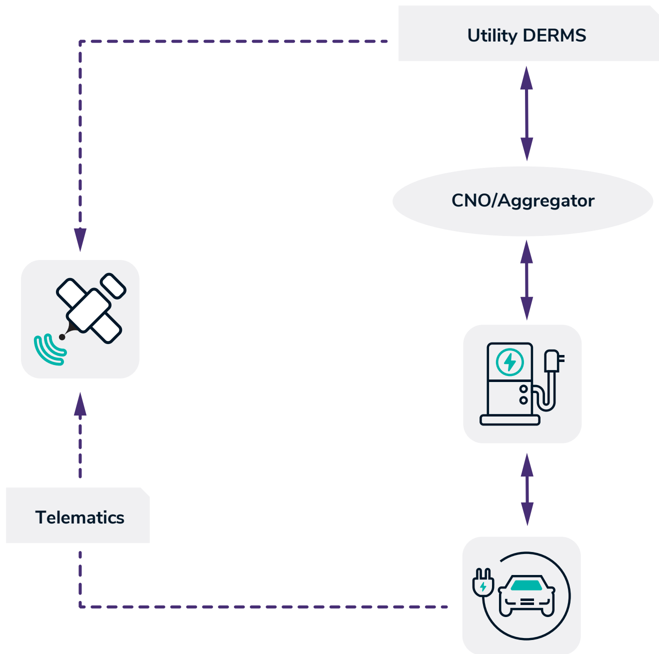


Figure 3: Basic V2G Communications Architecture

Key Point

The specific details of an architecture depend on where the AC-DC inverter is located, the control system for the inverter behavior and the interface to the utility.

V2G-DC Architecture and Standards

Figure 4 illustrates the major communications segments and key functional components of a V2G-DC system. The key communication segments are 1) between the grid operator DER Management System (DERMS) and an intermediary that manages multiple charging stations; 2) between the intermediary and the charging stations and 3) between the charging stations and the EVs. Multiple communications protocols can be certified and used for the required communications applications.

California's Rule 21 can accommodate bi-directional EVSEs that are certified to the UL 1741 interconnection safety standard (which implements the IEEE 1547.1 test specification for advanced inverters).[10]

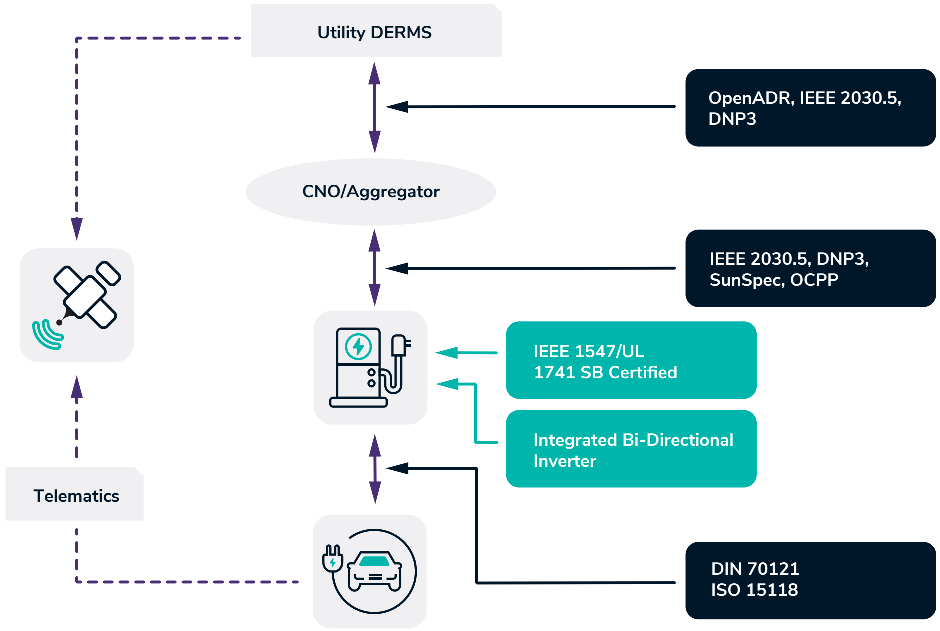


Figure 4: V2G-DC Architecture and Standards

For interconnection in California under Rule 21, the EVSE (which includes the bi-directional inverter) must be UL 1741 SB certified starting in 2023. The other requirement is that the CNO, Aggregator or other intermediary that communicates directly with the utility be IEEE 2030.5 CSIP certified.

Though not part of CA Rule 21, the state is moving towards mandating OCPP and ISO 15118 for CNO-EVSE and EVSE-EV communications.

Elsewhere in the US, other standards may be used for the utility-CNO/Aggregator link, including OpenADR, DNP3 and SunSpec. Nationally, the direction in the US is to mandate the use of ISO 15118 for EVSE-EV communications[11] and OCPP for CNO-EVSEs.

10. Per CPUC Resolution E-5165, V2G-DC systems can currently be interconnected.
11. Proposed Rule June 6, 2022, Executive Summary at https://www.federalregister.gov/documents/2022/06/22/2022-12704/national-electric-vehicle-infrastructure-formula-program

The significant technical obstacles to V2G-DC today are the immature state of ISO 15118-20 and OCPP V2.01 which support bi-directional power flows.[12] Further, since neither standard supports the full range of IEEE 1547-2018 requirements, the implementation of a standardized V2G infrastructure coexistent with this charging infrastructure will be challenging.

It is also of note that currently all of the V2G-DC pilot projects use proprietary communications.[13]

V2G-AC Architecture and Standards

Figure 5 illustrates the major communications segments and key functional components of a V2G-AC system. For V2G-AC, key standards are still in development.

Although ISO 15118-20 supports bi-directional power flows, it does not support the IEEE 1547-2018 grid support requirements. The standards in progress today that are most advanced for V2G-AC are based on the SAE J3072 standard but are still in development.

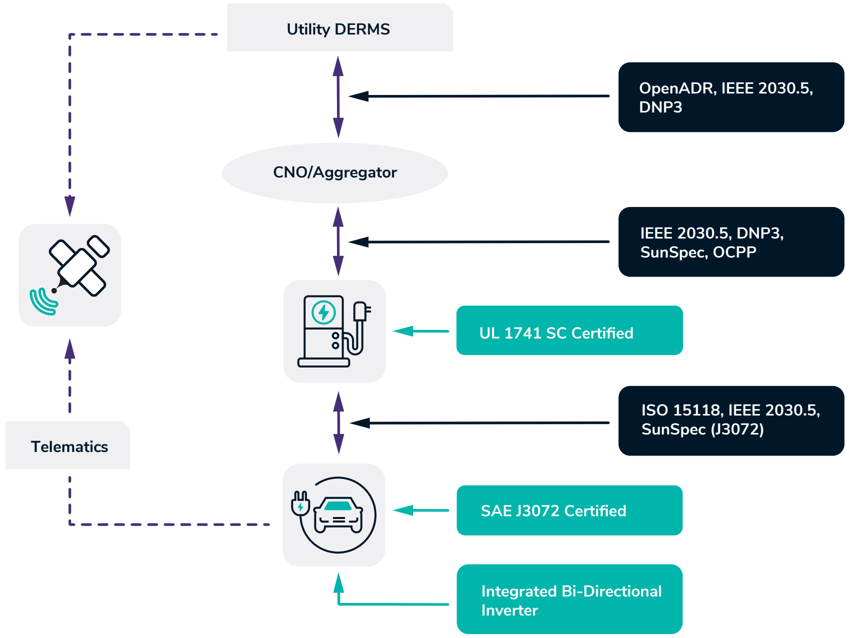


Figure 5: V2G-AC Architecture and Standards

Interconnection in California under Rule 21 is waiting for the standards to be completed and test and certification programs in place. The EV (which includes the bi-directional inverter) is expected to be certified to meet SAE J3072 requirements. The EVSE is expected to be certified under UL 1741 SC when it is completed. Both the EV and EVSE are expected to be required to certify their EV-EVSE communications to a SunSpec J3072 protocol certification program that is in development.

12. Neither revision of these standards is backward-compatible and neither has a test specification completed let alone a test and certification program as of Q1 2023.
13. Private conversation with an EV OEM

Currently, there are no plans by SAE, UL or any other appropriate organization to conduct certification testing of EVs for J3072 compliance. The EV OEMs are undertaking self-certification in lieu of a formal industry program.[14]

The UL 1741 SC test specification is under development and covers the certification testing requirements for the EVSE in a V2G-AC application. The J3072 protocol certification program is under development by SunSpec[15] and will consist of versions for both IEEE 2030.5 and SunSpec Modbus communications between the EVSE and EV.[16]

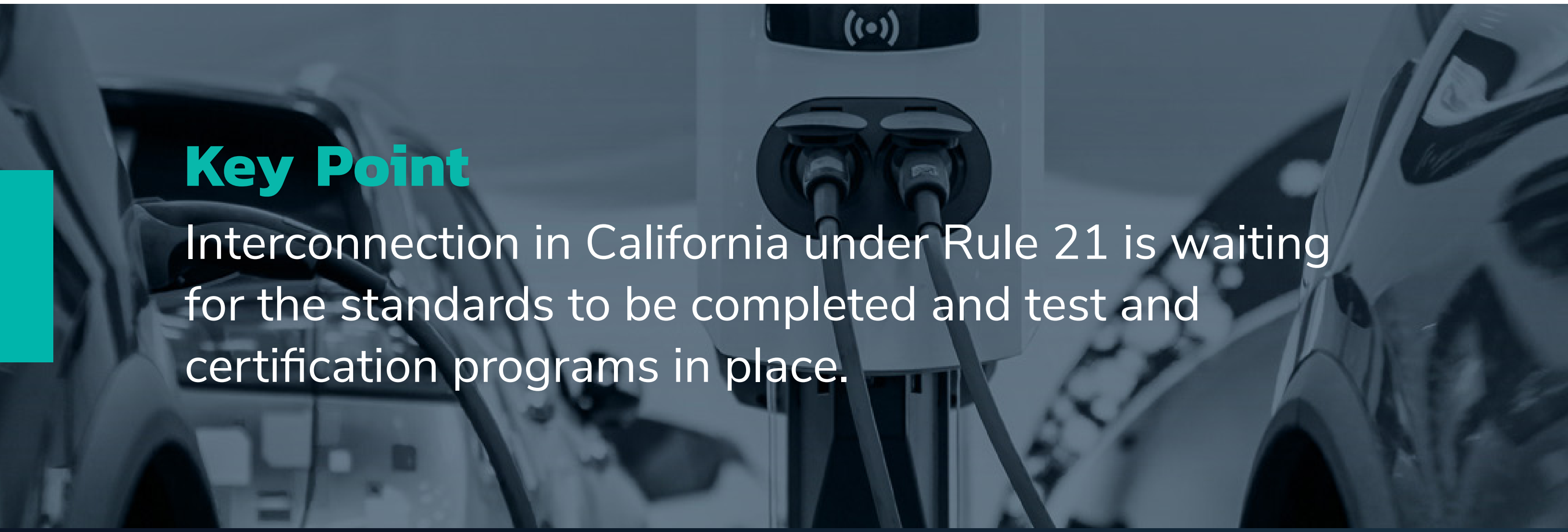
The requirement that the CNO, Aggregator or other intermediary that communicates directly with the utility be IEEE 2030.5 CSIP certified is the same for both V2G-DC and V2G-AC.

As noted above, California is moving towards mandating OCPP and ISO 15118 for CNO-EVSE and EVSE-EV communications. This creates a potentially complex environment with OCPP/ISO standards managing charging sessions and SAE/IEEE/UL standards managing V2G discharge sessions.

Elsewhere in the US, other standards may be used the utility-CNO/Aggregator link, including OpenADR, DNP3 and SunSpec. Nationally, the direction in the US is to mandate the use of ISO 15118 for EVSE-EV communications[17] and OCPP for CNO-EVSEs.

The significant technical obstacles to V2G-AC today are two-fold: the immature state of UL 1741 SC, SunSpec J3072 Profiles and the lack of certification programs for these standards and the emerging ISO 15118/OCPP charging infrastructure that is inherently not compatible with V2G requirements.

14. Traditionally the automakers have self-certified their own safety and intend to do so with V2G. However, utilities are reluctant to accept certification that is not done by a third party like UL. This issue is yet to be resolved but is a critical factor for V2G scaling.
15. See [Specifications - SunSpec Alliance for the IEEE 2030.5/V2G AC Profile Specification]
16. SAE J3072 specifies the use of IEEE 2030.5 for EV-EVSE communications for Type A1 charging systems (single phase in the US) and SunSpec Modbus for Type B1 charging systems (3-phase in the EU).
17. Proposed Rule June 6, 2022, Executive Summary at https://www.federalregister.gov/documents/2022/06/22/2022-12704/national-electric-vehicle-infrastructure-formula-program



Key Point

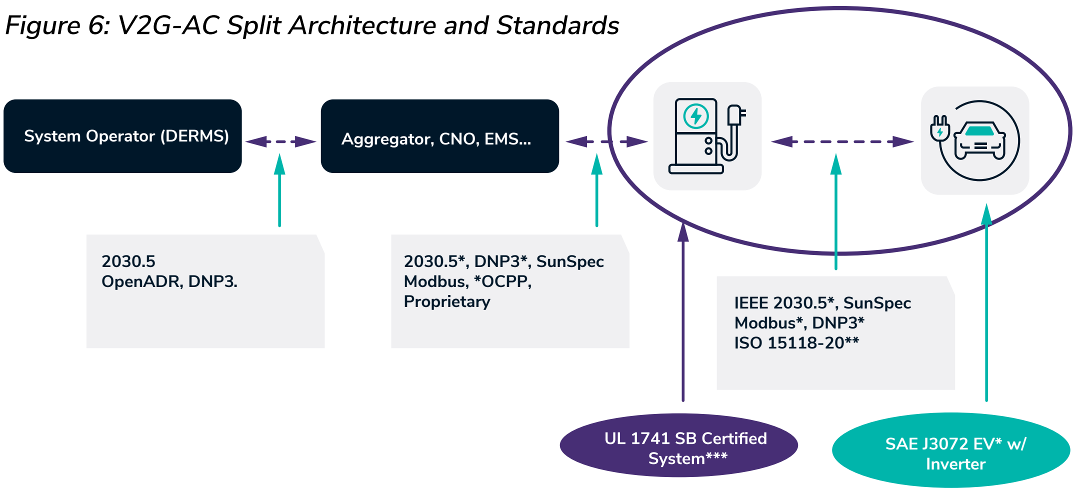
Interconnection in California under Rule 21 is waiting for the standards to be completed and test and certification programs in place.

Split Inverter Architecture and Standards

An emerging V2G architecture is what some call a “split inverter”, where some grid support functions are on the EVSE and others are in the EV itself. This model is receiving more attention as a method to reconcile a charging infrastructure that does not support V2G with the opportunities to implement V2G use cases in the current infrastructure.

There are not currently standards and certification programs in place to support such systems. A simplistic approach is to consider the EVSE-EV combination as a single DER and certify the combined system as a UL 1741 SB DER. This may work for use cases in which an EV is almost always charging at the same EVSE – e.g., residential or workplace Level 2 or DC Fast Charger. We see no reason this couldn’t be done today with existing tools and certification programs. Plugging into other EVSEs would be for charging purposes only and not eligible as a V2G DER.

Figure 6: V2G-AC Split Architecture and Standards



Key Point

The split inverter model is receiving attention as a method to reconcile a charging infrastructure that does not support V2G with the opportunities to implement V2G use cases in the current infrastructure.

Comparing EV Communications Standards

As the title to this paper suggests, we find that there is a lot of confusion about the standards for V2G. This is partly because the whole domain is relatively new and key standards are still being developed. Confusion also stems from the V1G vs V2G use cases: one requires utility interconnection while the other does not. The standards are different for the two use cases.

Further confusion arises from the difference between charging only applications and those that integrate EV charging and batteries into grid operations. Yet another factor is the architecture and the application of standards to different communications segments of Vehicle-Grid-Integration. Finally, the potential use of auto manufacturer's Telematics systems adds one more option and potential source of confusion about the standards.

To help in understanding which standards apply where and for which application, we've developed some simplified tables. Table 1 shows the major standards relevant to V2G and which communications segment they are used in. For instance, ISO 15118-2 is only applicable to the EVSE-EV communications while OpenADR is primarily used between a utility DERMS and an intermediary (aggregator, CNO, Fleet Operator, etc.) or between the DERMS and a Telematics platform.

Table 1: V2G Standards and Communications Segments

Protocol / Standard	DERMS-Int*	DERMS-Telematics	Int*-EVSE[18]	EVSE-EV[18]
OpenADR	√	√		
IEEE 2030.5	√	√	√	√
DNP3	√	√	√	√
SunSpec Modbus			√	√
OCPP			√	
ISO 15118-2				√
UL 1741 SB			√	
UL 1741 SC (J3072)			√	√

* "Int" = Intermediary such as an aggregator, charge network operator, site controller, etc.

Because standards specify either communications or functional requirements (or both), we've included the primary functional requirements specifications for V2G that enable utility interconnection of distributed energy resources like energy storage. These apply to EV power and energy export as well.

18. UL 1741 SB and J3072 include potential certification with DNP3 because of their IEEE 1547 Interoperability requirements. However, we are not aware of anyone using or planning to use DNP3 for these communications segments.

Table 2 shows which standards are used for which use case: V1G vs V2G-DC and V2G-AC.

Table 2: V2G Standards and Use Case Applicability

Protocol / Standard	V1G	V2G-DC	V2G-AC
OpenADR	√		
IEEE 2030.5	√	√	√
DNP3		√	√
SunSpec Modbus		√	√
OCPP	√		
ISO 15118-2	√		
UL 1741 SB		√	
UL 1741 SC (J3072)			√

There clearly could be a great deal more analysis of the standards and how they compare, but except for a deeper look at ISO 15118 and OCPP, those analyses are not in scope for this paper.

V2G Challenges in an ISO 15118/OCPP Charging Infrastructure

Both the California Energy Commission and the US Department of Transportation are proposing to mandate ISO 15118 and OCPP as requirements for EVSEs funded by government programs.

The California Energy Commission is investing in two programs to address charging interoperability problems with ISO 15118 and OCPP.[19] In February 2022, the Commission Staff published a recommendation for implementing ISO 15118-Ready Chargers.[20]

In February 2023, the US Department of Transportation issued a "Final Rule", effective March 30, 2023, for the "National Electric Vehicle Infrastructure Standards and Requirements".[21] The Proposed Rule specifies both ISO 15118 and OCPP as part of the National Electric Vehicle Infrastructure Formula Program aimed investing $7.5 billion in building a national charging infrastructure for electric vehicles. The proposal includes specific references to the interoperability challenges and the proposed adoption of standards to address them.

19. California Energy Commission selects DEKRA to establish Vehicle-grid Innovation Laboratory (ViGIL) (climate.brussels) and RFP-21-601 - Vehicle Interoperability Testing Symposium (VOLTS) (ca.gov). The contract has been awarded. See VOLTS 2023 – CharIN
20. "Implementation of AB 2127 Electric Vehicle Charging Infrastructure Assessments", February 24, 2022, Docket # 19-AB-2127, TN# 241955.
21. EV Charging Minimum Standards Rule as Submitted to Federal Register for Publication (Unofficial) (dot.gov)

Minimum national standards are identified for six areas including:

(2) Interoperability

(5) Network connectivity for EV charging infrastructure

Section 680.108 Interoperability of Electric Vehicle Charging Infrastructure includes the statement that:

> "(a) Charger-to-EV communication. Chargers must conform to ISO 15118-3 and must have hardware capable of implementing both ISO 15118-2 and ISO 15118-20. By February 28, 2024, charger software must conform to ISO 15118-2 and be capable of Plug and Charge. Conformance testing for charger software and hardware should follow ISO 15118-4 and ISO 15118-5, respectively."
>
> "(b) Charger-to-Charger-Network Communication. Chargers must conform to Open Charge Point Protocol (OCPP) 1.6J or higher. By February 28, 2024, chargers must conform to OCPP 2.0.1."
>
> "(c) Charging-Network-to-Charging-Network Communication. By February 28, 2024, charging networks must be capable of communicating with other charging networks in accordance with Open Charge Point Interface (OCPI) 2.2.1."

While these are major steps towards standardizing the charging infrastructure in the US, they also present significant challenges for a V2G infrastructure. ISO 15118 is designed around the EU distribution grid which is fundamentally different from the US electrical grid. The US, with long feeders and 110V customer circuits, requires generators to follow a set of voltage, frequency and reactive power controls that are not present in Europe.

The US topology DER interconnection requirements are reflected in the grid Smart Inverter controls defined under IEEE1547:2018. The EU topology is reflected in the EN 50549-1 and -2 standards.[22]

- ISO 15118 is driven mainly by European automakers and historically did not support V2G bi-directional applications. A new version, ISO 15118-20 has just been published and supports bi-directional power flows and some EU-oriented inverter controls. However, there is not yet a test specification nor a certification program and the standard is deficient for the US distribution grid:[23]

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22. See EPRI Presentation "ISO 15118-20 Review: US Context", August 1, 2022 and Mike Bourton (Kitu) "V2G – No Shortage of Standards" presented at the 9th Annual DR and DER Forum, October 13, 2022, San Diego.
23. EN 50549-1/-2 Requirements for generating plants to be connected in parallel with distribution networks - Part 1: Connection to a LV distribution network - Generating plants up to and including Type B - part 2 Connection to a MV distribution network - Generating plants up to and including Type B.

- The current ISO 15118-2 standard that is being implemented by industry globally does not support bi-directional power flows and has optional security requirements. The V2G implementations currently in place and under development rely on proprietary extensions of ISO 15118-2 and are not standardized.
- The basic control model for ISO 15118 is that the EV dictates the behavior of the EVSE – e.g., when to charge and when to stop charging. The basic DER model for the US distribution grid is based on EVSE control of the EV charging/discharging behavior. The two models need to be reconciled.
- ISO 15118-20 supports bi-directional power flows but with limited power quality messages: Max/Min Power Discharge, Max Discharge Current; Minimum Voltage; Current/Target Active Power; Target Reactive Power and Target Frequency. Missing are high/low voltage/frequency ride-through curves, Power Factor settings, etc.
- Neither OCPP nor ISO 15118-20 support messaging from a grid operator of the IEEE 1547-2018 curves and controls. There are also nameplate and configured ratings and status information required to be communicated from the EV DER system to the grid operator that is not supported in ISO 15118-20 and OCPP v2.01.
- Unfortunately, neither ISO 15118-20 nor OCPP v2.01 are backwards compatible so manufacturers of both EVs and EVSEs will need to develop new code bases and solve the interoperability problems that are expected with more complex message exchanges and use cases. The industry is currently struggling to solve these problems for ISO 15118-2 and OCPP v1.6, the current adoption targets for the industry. Adding the bi-directional functions and new versions will only add additional complexity and challenges to the interoperability issues.

ISO 15118-20 and OCPP 2.01 do make major progress in supporting V2G applications but there is a great deal of work to do before they can support the US V2G requirements. While both standards communities have discussed supporting the US grid codes for V2G, the prospect of including these in the standards in the near-term is problematic given the adoption curve of the -20 and V2.01 standards themselves.[24]

The strategy of the US utilities and EV industry has been to develop a unique set of standards and applications to accommodate IEEE 1547-2018 grid requirements for V2G. These have been discussed in previous sections of this paper.

24. See for instance OCA's presentation at the EPRI IWC meeting in Seattle, November 2, 2022

The Role of IEEE 1547/UL 1741 and V2G Certifications

One of the major areas of confusion, especially for companies that have been focused primarily on building electric vehicles and systems designed for charging them (EVSEs), are the requirements for interconnection of energy resources to US grids. Those technical requirements are embodied in an IEEE standard, IEEE 1547. The latest version was published in 2018 and was a major update to accommodate distributed energy resources (primarily solar and battery storage) into grid operations. Those updates are only now being required by US jurisdictions.

IEEE 1547-2018 specifies grid support capabilities that the US electrical grid operators require of interconnected DERs. The requirements reflect the expectations of electric grids with significant DER interconnected resources and are designed to enable grid operators to maintain grid safety, stability, and reliability in the context of significant DER interconnected resources. The key advancements in IEEE 1547-2018 are the addition of more functionality and a requirement for interoperable communications.

As noted in the ISO 15118/OCPP discussion, the European grid operates differently and the origins of 15118/OCPP were primarily for charging of EVs. Since those eco-systems did not historically need to consider US grid support functions, the discussion and effort to adapt these standards to the US grid IEEE 1547 requirements is generating additional confusion in the industry.

One additional point of confusion is that there is not a “IEEE 1547” certification. Rather, UL uses the IEEE 1547 standard as a key component of it’s UL 1741 safety standard for interconnection of distributed energy resources. Figure 7 illustrates the relationship between progressive versions of IEEE 1547 and UL 1741.

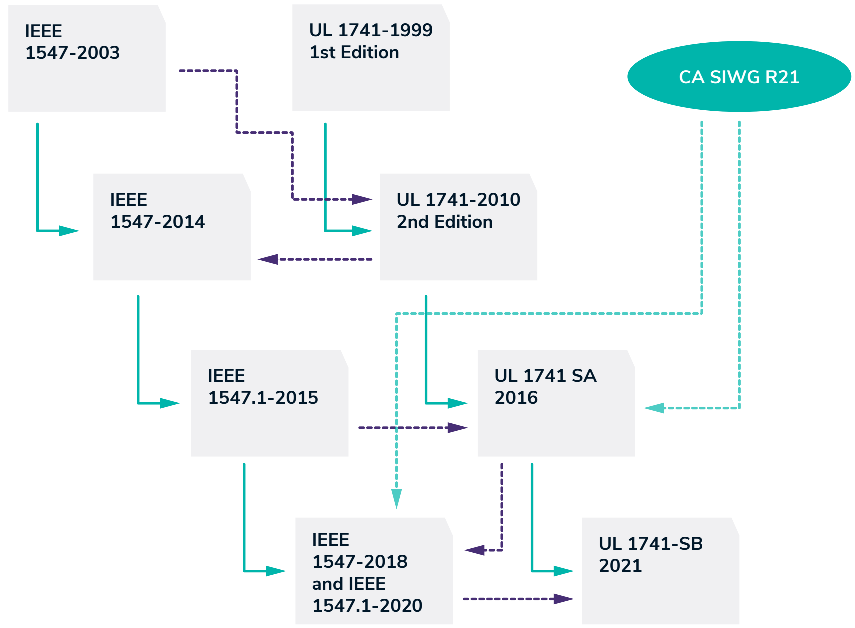

Figure 7: IEEE 1547 and UL 1741 Relationship

UL 1741 SB is primarily a safety standard to insure that interconnected DERs do not cause damage to the grid or cause other safety issues such as electrocuting an installer or catching fire. But the new functions defined in IEEE 1547-2018 also enable inverter-based DERs to provide grid support services not previously available. The standard applies to any DER:

- PV Solar
- Fuel Cells
- Micro-turbines
- Wind and Hydro Turbines
- Generator Set Interconnection Controllers
- Battery storage systems

UL 1741 covers numerous testing functions that are not addressed in IEEE 1547 such as:

- Physical construction requirements (electrical ratings of components, enclosures, etc)
- Fire hazards – product does not emit sparks, flames or molten metal
- Temperature testing – worst case operating conditions
- Markings, Ratings and Instructions
- Electrical safety testing
- System reliability
- EMC – Electromatic Susceptibility Tests
- And more safety tests like Humidity, Thermal Cycling, Transient Overvoltage

But the UL 1741 standard also does "Type" testing to validate the functionality required by IEEE 1547.1[25] and, for the latest update in 2018, UL 1741 SB includes all the Type and Interoperability tests as defined in IEEE 1547.1-2020. Table 3 shows all of the Type tests required for compliance to IEEE 1547-2018 and the Type tests used as part of the required Interoperability testing.

Table 3: V2G IEEE 1547.1 Type Tests and Interoperability Tests

Type Test	IEEE 1547.1 Reference	Interop Tests
Overvoltage Trip	5.4.2	√
Undervoltage Trip	5.4.3	√
Low-voltage Ride-Through	5.4.4	
Unbalanced Voltage	5.4.5	
Unbalanced Voltage	5.4.7	
Over frequency Trip	5.5.1	√
Under frequency Trip	5.5.2	√
Low-frequency Ride-Through	5.5.3	
High-frequency Ride-Through	5.5.4	
Rate of Change of Frequency	5.5.5	
Voltage Phase-Angle Change Ride-Through	5.5.6	

Type Test	IEEE 1547.1 Reference	Interop Tests
Enter Service	5.6.2	√
Unintentional Islanding	5.10	
Powerline Permissive Signal	5.10.3	
Minimum Import Active-Power	5.10.5	
Limit Active Power	5.13	√
Constant Power Factor	5.14.3	√
Voltage-Reactive (Volt-Var)	5.14.4	√
Voltage-Active (Volt-Watt)	5.14.9	√
Active Power (Watt-Var)	5.14.7	√
Contact Reactive Power	5.14.8	√
Frequency-Droop	5.15.2	√

25. IEEE 1547 is the base standards and IEEE 1547.1 is a companion testing standard used to validate compliance to IEEE 1547 requirements.

UL 1741 SB (also known as UL 1741 Edition 3[26]) is the latest version of the testing standard and can take as long as 12 weeks to be completed by an authorized test lab.[27]

The Interoperability testing can only be completed by using one of three named protocols to demonstrate that a certified inverter system performs a sampling of Type functions correctly when instructed in one of the three protocols. The named protocols are IEEE 2030.5, SunSpec Modbus and IEEE 1815 (known as DNP3). The three protocols were selected based on their support for the functions and settings required in IEEE 1547-2018 and their harmonization with the IEC 61850-4-720 DER Information Model. While a certified UL 1741 SB DER must demonstrate interoperability with one of the three protocols, requirements to actually use a particular protocol are determined by utilities and their regulators.

Since neither OCPP nor ISO 15118 support the required information model or the range of functions and settings required by IEEE 1547-2018, they are not considered valid protocols for interconnecting V2G DERs to US grid operations. They are not included in IEEE 1547-2018. An update to IEEE 1547-2018 is kicking off in 2023 and, if OCPP and/or ISO 15118 supports the required grid codes, it is possible that one or both could be included as an interoperability protocol in the next version of IEEE 1547.

V2G Standardization Progress in the US

The standardization of V2G communications infrastructure for the US is progressing in a context of 1) likely standardization of the charging infrastructure around ISO 15118 and OCPP and 2) various demonstration projects that are using customized communications solutions (in lieu of mandated standards) and 3) a growing demand for V2X solutions from EV buyers.

California: V2G Vanguard State

The State of California is arguably in the vanguard with respect to standardizing V2G.

Rule 21 is the interconnection tariff for CA IOUs (SCE, PG&E, SDG&E) as regulated by the CPUC. It specifies IEEE 2030.5, as defined by the Common Smart Inverter Profile (CSIP), as the default DERMS communications to Aggregators (aka CNO), customer site controllers, gateways, or DERs themselves. While not specified for communications with EVSEs or EVs, requiring IEEE 2030.5 for the first segment of communications to manage V2G operations encourages adoption of the protocol for downstream segments.

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26. Published September 28, 2021. Download the standard at UL Standard | UL 1741 (shopulstandards.com).
27. The US Occupational Safety and Health Administration (OSHA) manages the Nationally Recognized Testing Laboratory Program (NRTL). UL 1741 is one of the many standards that OSHA certifies labs as approved to conduct the testing for. See OSHA's Nationally Recognized Testing Laboratory (NRTL) Program | Occupational Safety and Health Administration.

CPUC Resolution E-5165 added interconnection of V2G-DC and V2G-AC systems to Rule 21 regulations. V2G-DC systems can currently be interconnected if they are certified to UL 1741 SA and, starting in April 2023, UL 1741 SB certification will be required.

V2G-DC systems can be connected as V1G as long as they have a UL Power Control Systems certification to ensure that they will not inadvertently switch to bidirectional mode and discharge to the grid and the factory default settings are set to unidirectional mode only. If such systems someday are to be used as V2G, the owners must apply for interconnection under Rule 21 as V2G systems.

Per CPUC Resolution E-5165, V2G-AC systems can be interconnected on a Pilot basis as V2G-AC standards are being completed. Such a pilot interconnection requires that a relay to be used to ensure disconnect in the event of anomalous grid conditions. OnceV2G-AC standards and testing/certification programs are completed and operational, the CPUC will convene a working group to determine the V2G-AC interconnection path forward in regard to:

- Required certifications
- IOU Interconnection Portals
- Processes
- Any other necessary clarifications and requirements

Status of Key Standards for V2G

Table 4 summarizes the status of key V2G standards for the US as of the end of 2022. The standards selected for this table are the three IEEE 1547 named protocols (IEEE 2030.5, DNP3 and SunSpec Modbus), OpenADR because of its V1G application, OCPP and ISO 15118. We've split ISO 15118 into the current protocol being adopted (-2) and the latest version that can apply to V2G (-20).

We've also included UL 1741 SB and SC standards since they are the two interconnection standards that will be used in the US for V2G systems. There are other standards that may be applicable, but these are the ones that currently lead in the current demonstrations and standardization discussions.

The first column denotes whether or not the standard is an internationally adopted standard. Column 2 shows if an EV specific profile has been or is being developed. In the case of EV specific protocols like ISO 15118 and OCPP, this is a given. But for other protocols, the adoption for a V2G use case is very much dependent on having a specific EV Profile and certification program.

Table 4: EV VG1 Standards Status, December 2022

Protocols	International Standard	EV Profile	EV Certification
OpenADR	√		**None**
IEEE 2030.5	√	√	**J3072 in Development**
DNP3	√		
SunSpec Modbus		**J3068 To Be Developed**	**J3068 To Be Developed**
OCPP	**IEC in Process**	√	√
ISO 15118-2	√	√	**Pending**
ISO 15118-20	√	√	**Not Started**

Interconnection Standards	International Standard	Application	EV Certification
UL 1741 SB	√	**V2G-DC**	√
UL 1741 SC	**In Development**	**V2G-AC**	**In Development**

ISO 15118-20 Notes

- Supports bi-directional power flows for V2G
- However, does not support IEEE 1547 interconnection requirements in the US
- Just published. Work on a test specification just starting

US Interconnection Standards

- IEEE 1547 does not recognize OpenADR, OCPP or ISO 15118 as protocols that can support V2G applications in the US.

The last column concerns actual certification program development and status. For instance, only UL 1741 SB is currently an operating certification program so only interconnections that require a UL 1741 SB certification can be made in a standardized method. Today that is V2G-DC only and only in CA.

A short summary of these standards status is below:

- **OpenADR.** OpenADR is relatively mature with a certification program that started in 2014 and over 40 EVSE vendors with certified OpenADR products. The primary use is for managed charging (V1G) but the OpenADR capabilities could be leveraged for V2G if OpenADR is only used to communicate a grid need for more energy and voltage support. But it would require another system with use of a different protocol to manage actual DER devices. The OpenADR Alliance is considering updates to the specification that could enhance its capabilities for V2G. But these are not yet finalized. OpenADR includes built in TLS 1.2 and other security features.
- **IEEE 2030.5.** This is the only protocol that could potentially be used throughout the V2G architecture from the grid operator DERMS all the way to the EVSE. It is the default mandated protocol for CA Rule 21 from the utility DERMS and the CSIP certification program is specific to DERs (although not EVs or EVSEs as DER). It is specified in SAE J3072 for single phase EVSEs and has a newly released Profile for J3072 for V2G-AC. We expect a SunSpec certification program for the IEEE 2030.5 J3072 Profile in the next year. IEEE 2030.5 includes built in TLS 1.2 and other security features.
- **DNP3.** This is an IEEE specification (IEEE 1815) and is used primarily in SCADA applications where real-time direct control of utility-owned and operated systems is the primary use case. It is included because it is an IEEE 1547 named protocol. Work in the MESA Alliance to standardize storage management using DNP3 could someday be leveraged for EV fleet V2G applications. DNP3 does not include native security features and does not have an EV specific profile or certification program today.
- **SunSpec Modbus.** This is a lower-level protocol intended for local control of solar inverter systems. However SunSpec Modbus is an IEEE 1547 named protocol and is specified in SAE 3068 for communications between an EVSE and EV for three-phase charging systems. Work has not yet started on a profile specific to SAE J3068 but it is expected to begin in the next 1-2 years. SunSpec Modbus does not have built-in security functions and is not yet an international standard.
- **OCPP.** Managed by the Open Charge Alliance, OCPP is EU based and associated closely with ISO 15118. Version 1.6 is currently being implemented by industry but does not support V2G in any form. There is a certification program with a large number of certified OCPP 1.6 products. Version 2.0 supports ISO 15118-20 bi-directional charging and security requirements but does not support IEEE 1547 messaging. An IEC version of OCPP is being worked on but could take up to 8 years to finalize. In the meantime, OCA is considering alternative strategies for supporting IEEE 1547 in the US.
- **ISO 15118.** The status and issues with ISO 15118 are summarized in a separate section of this report. As the likely mandated EVSE-EV standard for the US EV charging infrastructure, finding a way to support IEEE 1547 requirements in ISO 15118 is critical for adoption and scaling of V2G in the US.

- **UL 1741 SB.** As noted in a separate section of this report, UL 1741 SB is in the process of being adopted in the US as the interconnection certification required for grid support DERs in the future. This is the key certification required for an EVSE in a V2G use case and a number of EVSE vendors are working on gaining such a certification.
- **UL 1741 SC.** This is a new standard that is under development by UL and will define the testing and certification requirements for a V2G-AC EVSE in the US. The test specification uses the J3072 and related standards as the basis for the EVSE requirements to test against. Best estimate is a draft of UL 1741 SC will be available for balloting in 2023. This is a key certification that the CA CPUC is waiting on before finalizing its V2G-AC interconnection requirements.

Obstacles and Solutions to V2G Mass Adoption

There are significant obstacles to standardization and mass adoption of V2G technologies and programs. These obstacles are business, regulatory and technical in nature. While the business and regulatory obstacles are significant, QualityLogic's focus and the focus of this paper are on the technical obstacles. Our goal is to ensure a viable, interoperable, scalable infrastructure that can support whatever business and regulatory solutions are developed for V2G.

The technical obstacles to mass adoption of V2G technologies are greatest in the V2G-AC scenario. The standards and certifications for V2G-DC are mostly in place today except for the lack of support from ISO 15118 and OCPP. This requires a parallel communication path with OCPP to bring the IEEE 1547 settings to the EVSE and proprietary extensions to manage energy export from the EV. SAE 2847/2 is being developed to address the ISO 15118 shortfalls.[28]

For V2G-DC, the resolution to the technical obstacles is to complete the adoption and certification of the standards. Until ISO 15118-20 is adopted by the industry (there is not yet a test spec or certification program), the EVSE-EV communications will be proprietary to each vendor and scaling will be a challenge. The California Energy Commission is investing heavily in accelerating these standards in the US with its VIGIL and VOLTS programs.[29]

For V2G-AC, standardization is further from realization. SAE J3072 standards for the EVSE and protocols are in development, but the EV side certification has not yet been defined.

As noted in the earlier section on ISO 15118 and OCPP, the charging infrastructure will become the biggest technical challenge to realizing V2G use cases at scale in the US. As with most technical challenges, the solutions are a matter of time and investment.

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28. Protocol certification programs are in place for IEEE 2030.5, OpenADR, DNP3 and OCPP. For EVSE=EV communications, a certification program does exist for CCS/DIN SPEC 70121. See CharIN Conformance Testing – CharIN
29. California Energy Commission selects DEKRA to establish Vehicle-grid Innovation Laboratory (ViGIL) (climate.brussels)and RFP-21-601 - Vehicle Interoperability Testing Symposium (VOLTS) (ca.gov)

About QualityLogic

The global imperative to implement renewable electric power and transportation is challenging the industry to accelerate the integration of solar PV, storage systems, EVs and demand management systems into electric grid operations. QualityLogic is at the forefront of making this happen. Our deep expertise in communications standardization and interoperability is being used to accelerate development and adoption of key standards (OpenADR, IEEE 2030.5, IEEE 1547-2018) for the communications infrastructure that is essential for DER integration and coordination. Our contributions are test tools, training and support to the industry on key DER standards and the challenges of standardizing DER communications.

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